Disturbances of the Low Latitude Ionosphere During Extremes of Geomagnetic Activity

Michael Mendillo
Boston University
Center for Space Physics
phone: (617) 353-2629 fax: (617) 353-6463 email: mendillo@bu.edu

Award Number: N00014-03-1-0069
http://www.bu.edu/csp

LONG TERM GOALS

Various observational tools are available for the study of F-layer irregularities in the equatorial region. These include optical observations of the depletion of electron density, GPS phase fluctuations, DMSP in situ observations of ion depletions, radar observations of coherent scatter from equatorial irregularities, and ionospheric soundings. Each makes contributions to observational studies and each has its limitations. Our long term goal, using a full set of these measurements, is to study the physics of the equatorial regions, particularly during periods of irregularity development. Subsequent coupling of high latitude observations and equatorial observations will lead to forecasting where and when intense irregularities occur in various world areas and how they affect transmissions from satellites.

OBJECTIVES

Equatorial ionospheric irregularities, particularly in the region 10^o to 20^o north and south of the magnetic equator, are the cause of radio communications fades of up to 20 dB in episodic occurrence patterns. This latitude region includes cities such as Santiago, Bogota, Cairo and Singapore. Some receivers can deal with fades of this type (the flywheel effect, for example) while others cannot. Field program users of satellite-to-ground reception links need to know that problems are of natural causation rather than equipment malfunctions. Methods of dealing with the fading can only be designed using a knowledge of the geophysical and environmental characteristics of these irregularities (size, velocity etc.).

IMPACT/APPLICATIONS

Much of current understanding of the morphology patterns of communications-disruptive ionospheric irregularities comes from data taken at sites at or near the magnetic equator, such as Huancayo and Jicamarca (Peru) and Manila (Philippines). However, the very strongest amplitude and phase fluctuations of GPS and FLEETSATCOM signals come from stations in the so-called “Anomaly Region”, a latitude band in each hemisphere located between about 11^o to 20^o from the geomagnetic equator. In these regions, amplitude fluctuations to 20 dB have been noted, even at the high frequencies of GPS. Forecasting the timing and extent of communications dropouts due to ionospheric disturbances are the central applications products of the studies we are conducting.

Report Documentation Page					*Form Approved* *OMB No. 0704-0188*

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **30 SEP 2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**
4. TITLE AND SUBTITLE **Disturbances of the Low Latitude Ionosphere During Extremes of Geomagnetic Activity**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Boston University,,Center for Space Physics,, ,Boston,, ,02215**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Various observational tools are available for the study of F-layer irregularities in the equatorial region. These include optical observations of the depletion of electron density, GPS phase fluctuations, DMSP in situ observations of ion depletions, radar observations of coherent scatter from equatorial irregularities, and ionospheric soundings. Each makes contributions to observational studies and each has its limitations. Our long term goal, using a full set of these measurements, is to study the physics of the equatorial regions, particularly during periods of irregularity development. Subsequent coupling of high latitude observations and equatorial observations will lead to forecasting where and when intense irregularities occur in various world areas and how they affect transmissions from satellites.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

APPROACH

Our approach to studying geophysical disturbances as the cause of communications disruptions involves the use of unique (in house) regional data sets funded by ONR, state-of-the-art models (both empirical and computer simulation codes), in conjunction with global satellite observations available via the internet. Our own optical measurements involve all-sky camera observations of ionospheric structures taken at sites near the magnetic equator, as well as in the "Anomaly" region in the southern hemisphere. The latter come from our ONR-sponsored observing system at the El Leoncito Observatory in Argentina. To assess communications links, we study GPS signal phase fluctuations using an online network of over 60 ground stations throughout the Anomaly latitude band in both hemispheres. To understand the types of ionospheric structure disturbance responsible for the GPS effects, we use the sensors onboard the DMSP satellites that give direct ionospheric ion density measurements along each orbit.

The optical all sky measurements also allow us to identify unusual patterns of drift that occur during large-scale, solar-terrestrial disturbances known as geomagnetic storms. Our approach has been to study a number of individual storms and to search for characteristics that are common to all and thus capable of being forecast. Results obtained in the South American region are then tested at other longitudes (where we do not have optical data) using the GPS and DMSP satellites. In this way we are able to examine the longitude consistency and robustness of the forecasting techniques.

WORK COMPLETED AND RESULTS

Observations of plasma drifts in the equatorial region have been widely studied using satellite and ground based observations. The study of zonal (longitudinal) drifts of F-layer equatorial irregularities is of importance in that these irregularities produce phase and amplitude fluctuations on satellite signals. Signal fading effects occur over a broad range of frequencies used by DoD systems; they range from UHF FLEETSATCOM frequencies to INMARSAT gigahertz frequencies, and thus include GPS signals as well. Accurate specification of zonal drifts at different latitudes within the overall equatorial/low-latitude domain are needed for real-time and short-term forecasting of the motions of these plumes of irregularities as they drift eastward or westward.

Optical measurements spanning a million square kilometers are made possible by state-of-the-art, all-sky digital camera systems that record very faint emissions (sub-visual) from the nighttime ionosphere. The most severe irregularities are exclusively nighttime phenomena and so this technique is very well suited to our investigations. Using two such systems designed and fabricated at Boston University, we have made a coordinated series of observations at Arequipa (Peru) near the magnetic equator and at Tucuman (Argentina) at 14^{o} S magnetic latitude. Figure 1(a) shows these sites, as well as other locations with Boston University imaging systems. The Tucuman site is in the so-called Anomaly region of maximum electron density in the equatorial nighttime region and the area of deepest signal amplitude scintillations. These two datasets represent the first coordinated optical observations of this type, made in the same longitude sector and monitoring geomagnetic field lines that link both stations in latitude.

In the post sunset time period before 22 Local Time, the average zonal drifts for quiet magnetic conditions were found to be more rapid at the anomaly site (Argentina) than at the site on the magnetic equator (Peru). These results from Arequipa and Tucuman are shown in Figure 1(b). Later in the night, the average zonal drifts become higher at the magnetic equator (Peru) than at the anomaly site in

Tucuman. This reversal in the latitude of the site with the dominant drift following local time (before and after midnight) was not predicted by standard ionospheric models. Working in conjunction with colleagues at Utah State University (Vince Eccles) a new “electrodynamics model” provided the needed framework for the understanding the differing plasma drifts. These new results are part of the dissertation work of a Boston University graduate student from Tucuman and have recently been published in Martinis (2003).

The doctoral work of Ms. Marlene Colerico focused on observations and modeling of the thermospheric midnight temperature maximum’s (MTM) 6300 Å airglow signature, referred to as the midnight brightness wave (MBW). The MTM is a persistent, large scale, neutral temperature enhancement, ranging between 20-200 K, which forms at the geographic equator and propagates toward the poles. The MTM’s occurrence causes a cascade of effects in many upper atmospheric parameters. To date, state-of-the-art general circulation models have been unable to accurately reproduce the MTM and its upper atmospheric effects.

Colerico et al. (2003) combined the fields of view of the three southern hemisphere imaging systems shown in Figure 1 (a), Arequipa, Tucuman and El Leoncito, in order to extend the latitudinal coverage of MBW observations. The results highlighted the propagation of MBW events through the combined fields of view, providing the first evidence that the MTM’s upper atmospheric influence extends into mid-latitudes.

Figure 2 displays a composite averaged meridional 6300 Å brightness scans constructed from the averages of each of the selected data sets. An additional 6300 Å airglow feature, termed the pre-midnight brightness wave (PMBW), appears earlier in the evening. The averaged MBW and PMBW events are labeled and linear fits to the data are indicated by the black lines.

Colerico used output from NCAR’s thermosphere-ionosphere-electrodynamical general circulation model (TIEGCM), in collaboration with C. Fesen at Dartmouth, as input to our BU airglow code to model 6300 Å emissions in the equatorial region of the American sector. Colerico has also used the Naval Research Lab SAMI2 low latitude ionospheric model (in collaboration with J. Huba) and our airglow code to model the MTM’s airglow signature. SAMI2 employs the MSIS90 model for its neutral atmosphere and HWM93 for its neutral winds. The latter was replaced with the seasonally dependent analytical meridional wind equations of J. Forbes (Colorado) in order to examine what impact a wind modification similar to that produced by an MTM would have on 6300 Å airglow. The results, soon to be submitted for publication, represent the first successful simulation of an MBW event.

RELATED PROJECT

DURIP INSTRUMENTATION

A new Defense University Research Instrumentation Program (DURIP) grant was received during the past year and considerable progress was made in its implementation. The new instrumentation will allow us to study the intrusion of equatorial ionosphere disturbances into the mid-latitude domain. Two major perturbations are being studied: (1) Effects of ionospheric irregularities (ESF), and (2) Effects of the midnight temperature maximum (MTM) on the dynamics of the upper atmosphere system. Until recently, all of these studies have been done at low latitudes in the southern hemisphere. ESF is ordered by the geomagnetic field, and the MTM by geographic latitude. The new instrumentation will allow us to study both effects in both hemispheres.

The map in Figure 1(a) offers a graphical explanation of the roles of the new DURIP instruments. Our ONR-sponsored station in El Leoncito (Argentina) has a field of view (FOV) that include geomagnetic latitudes and apex heights (the altitudes above the geomagnetic equator to which magnetic field line extend) similar to those in the FOV of our NSF-sponsored station in Arecibo (Puerto Rico); El Leoncito's geographic latitude is similar to that at the McDonald Observatory (Texas), and thus is ideal to study MTM effects in the northern hemisphere. The DURIP grant will replace the damaged image-intensified-CCD camera in El Leoncito with a new state-of-the-art high efficiency CCD camera, and improve housing of the instrument. At McDonald, we will install a new all-sky optical system with a new CCD camera, and thus have a much needed way to monitor "ESF and MTM intrusions" into the low latitude domain.

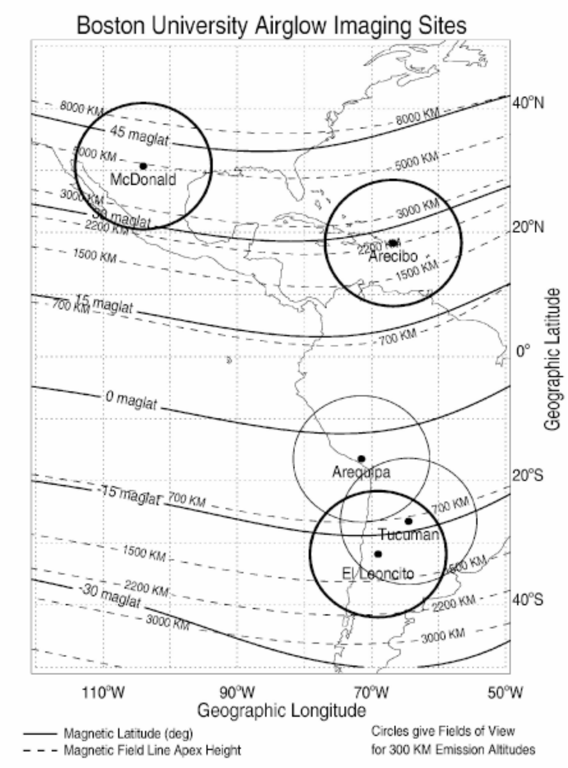
TRANSITIONS

In order to move towards the goal of forecasting the effects of ionospheric irregularities on communication system, we must understand the patterns of occurrence during both quiet and disturbed periods. The former is well in hand in that the seasonal-longitude patterns already determined are essentially regional forecasts of *ionospheric disruptive climate*. The day-to-day variability during those seasons remains the elusive topic. This type of *ionospheric weather* is under active study, and forecast techniques are within reach. The truly major challenge remaining is a serious one, to understand the role of geomagnetic storms in enhancing or inhibiting the occurrence of equatorial and low-latitude irregularities. This aspect of our study amounts to a determination of effects caused by *severe ionospheric weather,* and on a very localized level within several world regions. The analogy to tropospheric disturbances would be to tornadoes, i.e., very severe and very localized micro-climate. This area of research is not ready for a transition to operational use. Our current studies aim to do that, but many more storm studies are needed to establish confidence with testing for realistic, operational forecasting scenarios.

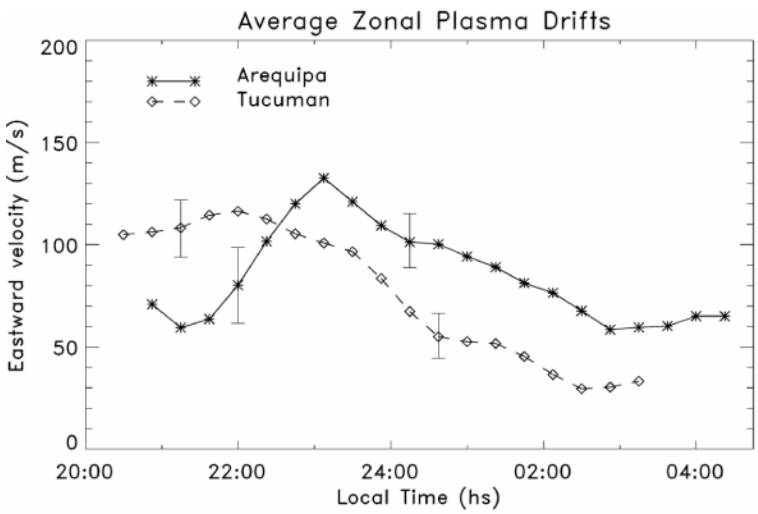
PUBLICATIONS

Colerico, M., M. Mendillo, C. Fesen, and J. Meriwether, Comparative investigations into the equatorial electrodynamics and low latitude coupling of the thermospheric system in the American Sector, Annales Geophysicae, submitted, 2003.

Martinis, C., V. Eccles, J. Baumgardner, R. Manzano and M. Mendillo, Latitude dependence of zonal plasma drifts obtained from dual-site airglow observations, J. Geophys. Res, 108 (A3), 1129, doi:10.1029/2002JA0009462, 2003.



(a)



(b)

Figure 1. (a) A map of the optical observing sites used in Boston University studies of equatorial and low latitude ionospheric processes. Coordinates are in geographic latitude and longitude, and the circles give fields of view for emissions at 300 km above each site. Also indicated are geomagnetic latitudes and apex heights (the altitudes above the geomagnetic equator that field lines reach). Past studies used instruments at Arequipa (Peru) and Tucuman (Argentina), and current ONR funded studies are at El Leoncito (Argentina) and at the McDonald Observatory in Texas. (b) Results of the Martinis et al. (2003) study of the eastward drift of ionospheric irregularities as a function of local time and latitude of each site. The pattern switch near 2300 local time is not adequately represented in most ionospheric models of the low latitude ionosphere.

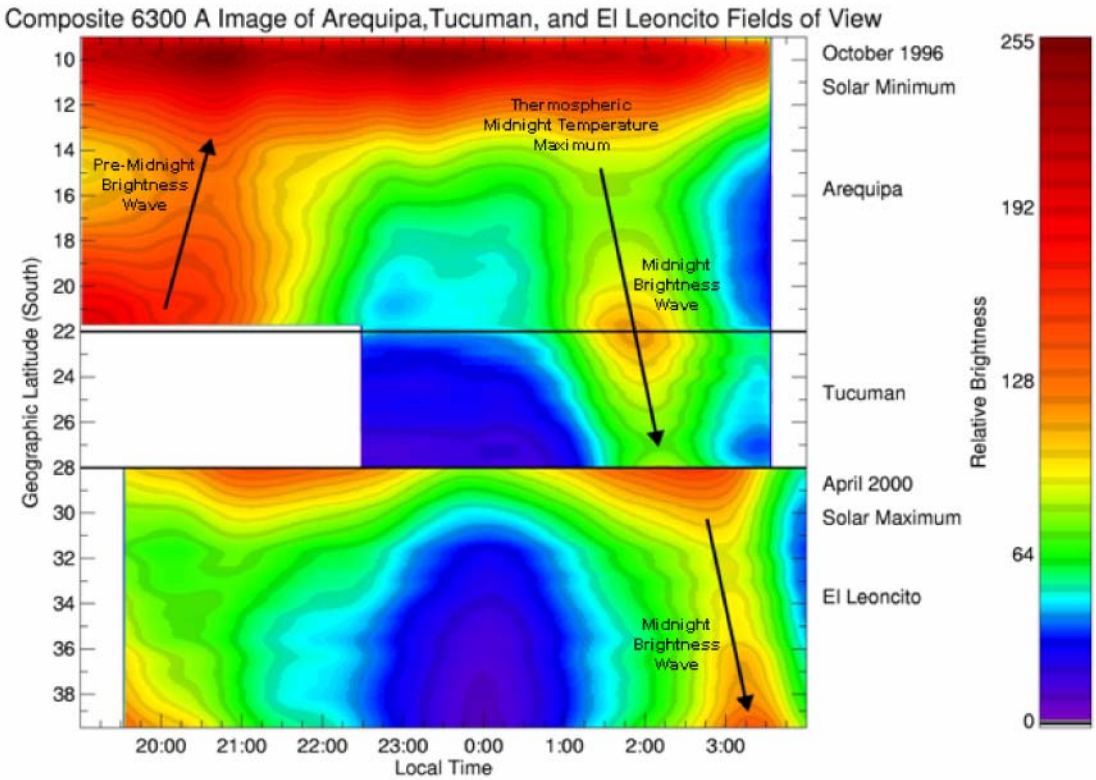


***Figure 2**. The midnight brightness wave is the 6300 Å airglow signature of the thermospheric midnight temperature maximum. Its apparent poleward propagation is related to the poleward modification in the meridional winds induced by the MTM which moves plasma down magnetic field lines to lowers altitudes where it can dissociatively recombine to produce enhanced 6300 Å emissions. The pre-midnight brightness wave is due to the relaxation of the equatorial anomaly crests and has an apparent equatorward propagation.*